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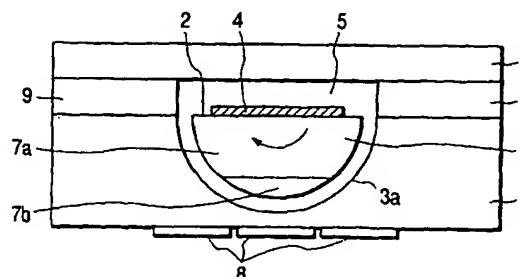
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### (54) Light deflection device and array thereof

(57) A light deflection device comprises a deflection member having a sphere body (71) enclosing a deflection face portion (72) for deflecting a light beam, or a segmental sphere body (1) having the deflection face portion (2) and a segmental sphere face opposing to the deflection face portion, a supporting member (73,3) for supporting the deflection member in a turnable manner, and a driving means for turning the deflection member, said driving means being provided on the sphere face (75a,b) or the segmental sphere face (7a,7b) of the deflection member, and at a position opposing to the sphere face (76a-e) or the segmental sphere face (8) of the deflection member to apply a driving force to the sphere face or the segmental sphere face.

A light deflection device array comprises the arrangement of light deflection devices in one-dimensional or two-dimensional array.

FIG. 4



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forces depend on the distance from the flat face of the hemisphere, or the tilt angle of the hemisphere, and the force application points (r1, r2) also depend on the tilt angle as shown in Figs. 1A and 1B.

[0008] A non-contact type driving mechanism as shown in Fig. 2A is disclosed in Japanese Patent Application Laid-Open No. 7-333528. In this constitution, hemisphere body 91 is supported only by contact portion of a conical pit. Therefore, when the attitude of the light deflection device is changed, for example reversed upside down as shown in Fig. 2B, the hemisphere is not supported. Thus, the attitude of the device is naturally limited to be controllable. In Figs. 2A and 2B, the numeral 92 indicates flat face portion; 93, a supporting member; 96 and 102, a driving electrode respectively; 100, supporting base plate; and 103, a spacer.

[0009] In the above constitution disclosed in Japanese Patent Application Laid-Open No. 7-333528, the turning center R and the gravity center G of the hemisphere as a turning body are apart at a distance r3 as shown in Figs. 3A and 3B. Therefore, with hemisphere body 91 and an optical oil having specific gravities different from each other, the resultant force Fg derived from gravity and buoyancy at the gravity center acts as a turning torque ( $F_g \times r_3$ ) disadvantageously. The turning torque of the resultant force at the gravity center remains after the hemisphere has been turned by the driving mechanism to a desired position. To keep the hemisphere body at the desired position, any of the following measures should be taken: (1) a compensation torque is kept applied, (2) the static friction coefficient is increased at the contact point with the concave, and (3) the resultant force from the buoyancy and the gravity is adjusted to be zero (that is, the specific gravities of the hemisphere body and the lubricating liquid are equalized).

[0010] The above measure (1) complicates greatly the control system in an array construction of the light deflection device. The above measure (2), although effective and practicable, is not compatible basically with the lubricity, tending to render insufficient the turn movement control and to cause deterioration of the parts by friction, and moreover, rendering the friction force ineffective in a certain attitude of the light deflection device. The above measure (3) is limited in reducing the specific gravity of the hemisphere body, and selection of the construction material especially when the refractive indexes of the optical oil and the hemisphere body are required to be equal in addition to the requirement for the specific gravity.

#### SUMMARY OF THE INVENTION

[0011] The present invention intends to provide a light deflection device which satisfies the requirements: (1) a larger deflection angle of a light beam, (2) deflection of incident light to any desired direction, (3) ease in control of a turning direction of a light deflection member like a hemisphere and control of a deflection angle of a light

beam, and (4) ease in miniaturization and linear or two-dimensional arraying of the device.

[0012] The present invention further intends, in addition to the above objects, to provide a light deflection device satisfying the requirements, in addition to the above objects: (5) controllability in any attitude of the device, and (6) excellent direction stability at a non-driven state.

[0013] The light deflection device of the present invention comprises a deflection member having a sphere body enclosing a deflection face portion for deflecting a light beam, or a segmental sphere body having the deflection face portion and a segmental sphere face opposing to the deflection face portion; a supporting member for supporting the deflection member in a turnable manner; and a driving means for turning the deflection member, the driving means is provided on the sphere face or the segmental sphere face of the deflection member and at a position opposing to the sphere face or the segmental sphere face of the deflection member to apply a driving force to the sphere face or the segmental sphere face.

[0014] With the above constitution, the force for turning the turning body, which shapes the sphere body or the segmental sphere body like a hemisphere body, is applied invariably to the torque application points on the spherical face or the segmental spherical face (hemispherical face) to prevent variation of the distance between the force application point and the turning center. Thereby, the turning direction of the turning body and the deflection angle are readily controlled. In the light deflection device of the present invention, the turning body is driven without contact of the driving means, and the driving mechanism is relatively simple, so that the device is suitable for miniaturization and arraying of the devices. Furthermore, with the light deflection device of the present invention, the controllable turning range of the turning body can be made relatively larger, whereby the deflection angle can be made larger to deflect the light beam to any desired directions.

#### BRIEF DESCRIPTION OF THE DRAWINGS

##### [0015]

Fig. 1A and Fig. 1B are schematic sectional views for explaining generation of a torque in a conventional light deflection device.

Fig. 2A and Fig. 2B are schematic sectional views for explaining a driving means in a conventional light deflection device.

Fig. 3A and Fig. 3B are schematic sectional views for explaining the relation between the gravity center and the driving torque in a conventional light deflection device.

Fig. 4 is a schematic sectional view showing a first example of the light deflection device of the present invention.

reflection face portion such as a flat face portion for reflecting deflection, and the light beam is introduced from the deflection face side or the segmental sphere body side to the deflection face and is deflected by reflection at the reflection layer established on the deflection face portion. In the deflection by refraction, the segmental sphere body is transparent to the light beam to be deflected, and the refractive index of the deflection face portion is different from that of the space in contact with it. The space may be filled with a liquid having a prescribed refractive index, whereby, light is deflected at the interface according to Snell's Law. This is advantageous in certain cases since the light-introducing side and the light-emitting side are opposite to each other relative to the segmental sphere body.

[0025] The light deflection device of the present invention is described in detail by reference to examples.

#### Example 1

[0026] Fig. 4 is a side sectional view of the light deflection device of a first example of the present invention. The light deflection device of this example comprises hemisphere body 1 having flat face portion 2 for deflecting an incident light beam, supporting member 3 for supporting hemisphere body 1 turnably in hemispherical concave 3a with a gap therebetween for turning of hemisphere body 1, and a driving means for turning hemisphere body 1. The driving means has chargeable regions 7a, 7b having different electric charging characteristics on the spherical face of hemisphere body 1 to turn hemisphere body 1. As shown in Fig. 4, chargeable region 7a is formed in a shape of a belt surrounding the hemispherical face, and chargeable region 7b is formed in a bowl shape at the bottom of the hemisphere body. Driving electrodes 8 are provided at the bottom portion of supporting member 3 to apply an electric field to charging regions 7a, 7b and vicinity thereof. The light beam is deflected at reflection layer 4 formed on flat face portion 2. The gap is filled with dielectric liquid 5 which is sealed by plane-parallel base plate 6 provided above hemisphere body 1 with interposition of spacer 9 not to prevent turning movement of hemisphere 1.

[0027] The driving method of Example 1 of the light deflection device of the present invention is described below in detail. A particle (hemisphere body 1) in dielectric liquid 5 like silicone oil exchanges electric charge with the liquid to form an electric double layer, whereby the particle is charged to be positive or negative. As described above, hemisphere body 1 of this Example has, on the spherical face, chargeable regions 7a, 7b having different charging characteristics in liquid 5. The spherical face is comprised partly of different materials ( $MgF_2$  and quartz glass as described later). Thereby the surface charging quantity of hemisphere body 1 in liquid 5 is also different between chargeable regions 7a, 7b, producing an electric moment in hemisphere body 1. (In Fig. 4, the vector of the moment is directed vertical

through the spherical center of hemisphere body 1.) On applying an electric field through driving electrode 8 to this hemisphere body 1, a torque is produced to equilibrate the pole direction of the electric charge (vector direction of the electric moment) of hemisphere body 1 with the formed electric field. Since the surface only is charged, the distance of the torque application point from the turning center is always equal to the radius of hemisphere body 1. When hemisphere body 1 has turned to equilibrate its charge pole with the electric field direction, the torque is offset to stop the turning movement. After the turning movement is stopped, hemisphere body 1 keeps the position fixed owing to friction between hemisphere body 1 and concave 3a, and other causes, even after the electric field is eliminated. On application of an electric field in a different direction by selecting driving electrode 8, a torque is produced to equilibrate the pole direction with the newly applied electric field to turn the hemisphere body similarly again. With the above driving means, no electric wiring to hemisphere body is necessary.

[0028] Fig. 5 is a plan view showing an example of arrangement of driving electrodes 8a, 8b, 8c, 8d and 8e relative to hemisphere body 1. With this arrangement of five electrodes 8a, 8b, 8c, 8d, and 8e, the method of driving of the light deflection device is explained in detail by reference to Fig. 6A and Fig. 6B. Hemisphere body 1 has negatively chargeable region 7b and positively chargeable region 7a, and is placed in dielectric liquid 5. An electric field is effected to this hemisphere body 1 by applying a positive voltage to central electrode 8b and a negative voltage to other driving electrodes as shown in Fig. 6A (8d and 8e at the front side and the back side are not shown in the drawing). Thereby, charged region 7b looks toward the driving electrode by bringing its charged pole in equilibrium with driving electrode 8b as shown 6A. In this state, the incident light beam at an incident angle  $\theta$  (shown in Fig. 6A) is reflected at a reflection angle  $\theta$ .

[0029] Then, switch SW1 is turned off and switch SW2 is turned on to apply a positive voltage to driving electrode 8a at the left side, and a negative voltage to other driving electrodes as shown in Fig. 6B (8d and 8e are not shown in the drawing). Thereby, hemisphere body 1 turns right around the spherical center in the drawing to equilibrate the charge pole direction of charged region 7b with the electric field direction to take a certain turning angle  $\alpha$ . Thereby, the reflected light beam is deflected further by an angle  $2\alpha$  in comparison with that shown in Fig. 6A. By switching over the switches SW1 and SW2 again, hemisphere body 1 returns to the position as shown in Fig. 6A. In the manner shown above, the hemisphere 1 can be driven to various positions. For example, hemisphere body 1 is brought to a position intermediate between the positions in Fig. 6A and Fig. 6B by applying independently positive voltages to driving electrode 8a and driving electrode 8b, and negative voltage to other electrodes, whereby a deflection of less

1. After the turning movement has stopped, hemisphere 11 keeps the position fixed, without the electric field application. On application of an electric field in a different direction, a torque is produced similarly to equilibrate the pole direction with the applied electric field to turn the hemisphere 11 similarly again. With the above driving means, no electric wiring to hemisphere body is necessary similarly as in Example 1.

[0036] The principle of the deflection in Example 2 is described below. When hemisphere body 11 is turned by an angle  $\alpha$ , relative to the incident light beam introduced through the bottom of supporting member 13, by the aforementioned driving means, the angle  $\beta$  of deflection from the incident light beam is shown by the equation below according to Snell's Law:

$$\beta = \sin^{-1}[(n_2 \cdot \sin \alpha) / n_1] - \alpha$$

where  $n_1$  is the refractive index of dielectric liquid 15, and  $n_2$  is the refractive index of hemisphere body 11.

[0037] Specifically, the light deflection device was produced in the same manner as in Example 1 except that hemisphere body 11 was prepared from a micro-bead having a refraction index of 1.9 and a diameter of 100  $\mu\text{m}$  for collimator lens, no reflection layer is formed on hemisphere body 11, and methyl alcohol of refraction index 1.33 was used as dielectric liquid 15. The arrangement of driving electrodes 18a, 18b, 18c, 18d, and 18e (18d and 18e being not shown in the drawing) relative to hemisphere body 11 was the same as that in Example 1. On application of a voltage of +100 between driving electrode 18a and other driving electrodes, hemisphere body 11 turned at angle  $\alpha$  of 20° as shown in Fig. 7. After stop of the turning movement, the angle  $\alpha$  was kept unchanged without the voltage application. From the above specific numerical values, the angle  $\beta$  was calculated to be 9° according to the above equation. That is, the reflected light beam was deflected by 9° relative to the incident light beam.

#### Example 3

[0038] Fig. 8 is a sectional side view of a third example of the light deflection device of the present invention. In this Example, driving electrodes 28 are formed on the face of concave 23a of supporting member 23 for supporting hemisphere body 21, and insulation layer 30 is formed on driving electrodes 28. Otherwise the constitution is the same as that in Example 1.

[0039] The deflection device of this Example comprises also hemisphere body 21 having flat face portion 22 for deflecting the incident light beam, supporting member 23 having a concave 23a for supporting hemisphere body 21 with interposition of a gap in a turnable manner. Chargeable regions 27a, 27b having different charging characteristics are provided on the spherical face of hemisphere body 21 for turning it. In the same manner as in Example 1, reflection layer 24 is formed on

flat face portion 22 to deflect the light beam by reflection. Above hemisphere body 21, spacer 29 is provided not to prevent the turning movement of hemisphere body 21. Dielectric liquid 25 is filled into the gap, and dielectric liquid 25 is sealed by base plate 26. The light deflection device of this Example turns hemisphere 21 by the same driving method as in Example 1.

[0040] The light deflection device of this Example is prepared in the same manner as in Example 1 except for the process for formation of supporting member 23. This process is described below. The upper face of a quartz glass plate is coated with a Cr (chromium) film and an Au (gold) film successively by electron beam vapor deposition to form a mask. A part of the Cr-Au mask is removed by a photolithography process and etching in a pattern of a circle. Through the pattern-removed portion, the quartz glass is etched off isotropically by an aqueous hydrofluoric acid solution. Then the Cr-Au mask is removed to form a hemispherical concave 23a for supporting hemisphere body 21 on supporting member 23. Then the inside face of hemispherical concave 23a is coated with Al (aluminum) by sputtering. From the aluminum layer, driving electrodes 28 are formed by photolithography process and etching as shown in Fig. 8. Driving electrodes 28 may be arranged similarly as that shown in Figs. 2A and 2B. On driving electrodes 28, insulating layer 30 is formed by sputtering silicon dioxide.

[0041] In the light deflection device of this Example, driving electrodes 28 are formed on the spherical face of hemispherical concave 23a of supporting member 23. Thereby, the distance between chargeable region 27a, 27b and driving electrode 28 is shortened, enabling lowering of the voltage for turning of hemisphere body 21.

#### Example 4

[0042] Fig. 9 is a side sectional view of the light deflection device of a fourth example of the present invention. The light deflection device of this example comprises a hemisphere body 31 having a flat face portion 32 for deflecting an incident light beam, and a supporting member 33 for supporting hemisphere body 31 in a turnable manner with a gap therebetween for turning of hemisphere body 31. However, in this Example, movable electrode 37 is provided at the bottom portion of the spherical face of hemisphere body 31 for turning of hemisphere 31, driving electrodes 38 for applying electric field to movable electrode 37 is provided at the bottom of supporting member 33, and fixed electrode 40 is formed on the face of spherical concave 33a of supporting member 33 for supporting hemisphere body 31. Fixed electrode 40 is wired from the outside, for example, along the face of hemispherical concave 33a. Hemisphere body 31 turns with movable electrode 37 in contact with fixed electrode 40. Fixed electrode 40 and driving electrodes 38 are connected to power source to

points on the hemispherical face and the other one supporting point outside the same hemispherical face. The above four supporting points are respectively placed nearly at a distance of the radius of the turning body from the turning center.

[0048] The above mechanism is described in more detail. The turning body is supported by at least four points not existing on one hemispherical face on the supporting member. With this constitution, the turning body can be supported stably when the attitude of the light deflection device is changed, for example even when it is turned upside down. The supporting member has a spherical or segmental spherical space (cavity). With more supporting points, the turning body can be supported stably at varieties of the attitude. In particular, the supportable range of the attitude of the turning body can be extended greatly by making the assemblage of the supporting points in a shape of a sphere or segmental sphere in the supporting member. The turning body may be supported with a gap between the supporting point and the turning body. The gap may be filled with a liquid to support the turning body by the liquid. The supporting space is preferably spherical or segmental spherical for holding the liquid in the gap.

[0049] The above constitution enables the embodiments below with advantages respectively.

[0050] The aforementioned driving means comprises typically a driving means provided on a surface of a turning body and a driving means provided on a supporting member or a position confronting the turning body with interposition of the supporting member. The non-contact electromagnetic driving means, which are provided on the surface of the turning body and on the supporting member or the position confronting the turning body with interposition of the supporting member, exert a turning force onto the spherical face. Therefore the point of action of the torque is invariably on the radius of the turning body without change of the distance between the action point and the turning center. Thereby, the turning direction and the deflection angle can readily be controlled. This light deflection device can deflect the light beam at a larger deflection angle, which enables light deflection to any desired direction. Furthermore, this driving means are non-contacting, which renders unnecessary electric wiring to the turning body surface, and is suitable for miniaturisation and arraying of the light deflection device.

[0051] More specifically, the driving means is constituted of regions having different charging characteristics formed on the surface of the turning body, and driving electrodes. The charging states of the regions having different charging characteristics are preferable formed by zeta potential generated at the interface between the dielectric liquid filled in the gap and the spherical face of the turning body, but may be formed by another method such as treatment for electret treatment. Another variation of the driving means comprises an electrode on a portion of the surface of the turning

body and a driving electrode, turning the sphere body by electrostatic attraction generated by application of a voltage between the electrode on a portion of the turning body and the driving electrode. A still another variation is constituted of a magnetic film formed on a part of the turning body, and an electromagnet provided on the supporting member side, where the rotation of the turning body is controlled by a magnetic force generated between the magnetic film and the electromagnet.

[0052] A still another variation of the driving means turns the turning body by application of an electric field between driving electrodes provided with interposition of the turning body on both sides thereof. In this driving means, the regions having different charging characteristics may be provided on the respective hemisphere regions of the sphere. In this constitution, the turning torque can be generated symmetrically at the both sides of the sphere to control the turning movement more quickly and more stably.

[0053] A further specific embodiment is applicable. A supporting member has a space (cavity) as mentioned above. A turning body is supported through a gap in a turnable manner. The gap is preferably filled with a liquid to support the turning body smoothly with high controllability.

[0054] The deflection face portion is typically a flat face. It may be a convex face or a concave face, if necessary. However, a light beam can be controlled more readily by the flat face portion.

[0055] The deflection of a light beam may be conducted either by reflection or by refraction. In practice of deflection by reflection, a reflection layer for deflection is formed on a deflection face portion like a flat face portion, and a light beam introduced from the reflection layer side or from the reverse side thereof to the deflection face portion is deflected by reflection. In deflection by refraction, the turning body is transparent to the light beam to be deflected, the light beam is deflected by refraction according to Snell' Law by utilizing difference of refractive index between materials constituting the interface (two materials on respective sides of the deflection layer, or the deflection face portion and the space in contact with it). The space may be filled with a liquid having a prescribed refractive index. The deflection by reflection is advantageous in a certain case since the light-introducing side and the light-emitting side are opposite relative to the turning body.

[0056] The dielectric liquid as the aforementioned liquid should be optically transparent and have a high insulation resistance. Although an organic solvent such as toluene, and acetone, or water may be used, non-volatile liquid is preferred not to volatilize from the cavity. Silicone oil is especially preferred which contains less ions and impurities and has high resistance. The electrode may be formed from a metal or a semiconductor having low resistance.

[0057] In the case where the light beam is introduced from the bottom side of the light deflection device, the

distance of the torque application point from the turning center of sphere body 71 is equal to the radius of sphere body 71.

[0067] When sphere body 71 has turned to equilibrate its pole direction with electric field direction, the torque is offset to stop the turning movement. Sphere body 71 has its turning center and gravity center at one and the same position, so that the resultant force derived from the gravity and the buoyancy does not produce a turning torque. Therefore, when the electric field application is stopped, no turning torque is applied, thereby sphere body 71 being held stably at the desired controlled position irrespectively of the static friction coefficient. Change of the direction of the electric field application produces torque to equilibrate the pole direction to the applied electric field, turning again sphere body 71 to a newly indicated position. Cavity 73c of supporting member 73 is spherically symmetrical, so that the position of the turning center can be kept fixed, and the position of sphere body 71 can be controlled irrespectively of the attitude of sphere body 71. Fig. 15B shows an example of arrangement of driving electrodes 76a-76e relative to sphere body 71 viewed from the top side of the light deflection device.

[0068] The method of drive of the light deflection device of this Example is described below in more detail by reference to Fig. 16A and Fig. 16B. In Figs. 16A and 16B, the reversed blank triangles show common electrodes. Sphere body 71 has a negatively chargeable region 75b and a positively chargeable region 75a, which are chargeable in dielectric liquid 74. To this sphere body 71, an electric field is given by applying a positive voltage to driving electrode 76b and applying a negative voltage to other electrodes 76a, 76c (76d and 76e being not shown in the drawing) as shown in Fig. 16A. Thereby, charged region 75b directs its pole to driving electrode 76b. Thus, an incident light beam introduced at an incident angle  $\theta$  to the reflection layer on flat face portion 72 is reflected at a reflection angle  $\theta$ .

[0069] Subsequently, as shown in Fig. 16B, switches 79a, 79b are changed over to apply the positive voltage to driving electrode 76a and the negative voltage to other driving electrodes 76b, 76c (76d and 76e being not shown in the drawing). Thereby, sphere body 71 is driven to turn to equilibrate the pole direction of charged region 75b with the electric field direction, sphere body 71 changing the attitude by turning angle  $\alpha$ . As the result, the reflected light from the reflection layer on flat face portion 72 is deflected by angle  $2\alpha$  in comparison with that in Fig. 16A. By changing over the switches to 79a, 79b, sphere body 71 is driven to return to the original position as shown in Fig. 16A. Further, the deflection angle of less than  $2\alpha$  can be obtained by applying a positive voltage to driving electrode 76a, and driving electrode 76b separately, and a negative voltage to other driving electrodes. After determining the dependence of the deflection angle on the voltage application state preliminarily, sphere 71 can be turned under con-

trol to obtain a desired deflection angle according to the memorized information on the dependence.

[0070] An process for production of the light deflection device of this Example is shown below. Sphere body 71 is prepared from micro-beads of about 100  $\mu\text{m}$  diameter of quartz glass for a collimator lens of light-emitting diode. The beads are partially cut by polishing to prepare two hemisphere bodies. The flat faces of the hemisphere bodies are bonded to an adhesive tape. Onto the spherical faces of the hemispheres,  $\text{MgF}_2$  is vacuum vapor-deposited by sputtering to form chargeable region 75a. Thereafter, a photoresist is applied onto the surface of the one hemisphere body. The photoresist on a predetermined region of the hemispherical face is developed by light exposure.  $\text{MgF}_2$  is removed by in etching with Ar to bare a portion of the quartz glass to form chargeable region 75b. Then, spherical face side of the other hemisphere body is fixed onto an adhesive tape. On flat face portion 72, an Al (aluminum) film is formed as the reflection layer by electron beam vapor deposition. The two hemisphere bodies are separated from the adhesive tape, and the photoresist is removed. An adhesive layer is formed on either one of the flat face portions. Finally, the two hemisphere bodies are bonded by using a registration apparatus equipped with hemisphere-holding pits, a microscope, and three-dimensional displacement controlling mechanism to complete a sphere body 71 which has chargeable regions 75a, 75b having different charging characteristics, and contains a flat face portion 72 having a reflection layer on the equatorial plane inside.

[0071] Supporting member 73 is also made from quartz glass. On the bottom face of the quartz glass plate, a transparent electroconductive ITO film is formed by vacuum vapor deposition, and driving electrodes 76a to 76e are formed through photolithography process and etching as shown in Fig. 15A and Fig. 15B. The upper face of this quartz glass is coated with a Cr (chromium) film and an Au (gold) film successively by electron beam vapor deposition to form a mask. A part of the Cr-Au mask is removed by photolithography process and etching in a pattern of a circle. Through the pattern-removed portion, the quartz glass is etched off isotropically by an aqueous hydrofluoric acid solution to form a hemispherical concave on lower supporting member 73b. Separately, upper supporting member 73a is prepared in the same manner except that the electrodes are not provided. Finally, sphere body 71 having the reflection layer, and chargeable regions 75a, 75b is placed in the hemispherical concave of lower supporting member 73b, and upper supporting member 73a and lower supporting member 73b are press-bonded with an adhesive in dielectric liquid 74 comprised of a silicone oil to enclose tightly dielectric liquid 74 and sphere body 71. Thus the light deflection device of this Example is completed.

[0072] The operation of the deflection device is described below. To the light deflection device prepared

field provided at the lower portion of supporting member 73. An incident light beam introduced from supporting member 73 is deflected at flat face portion 72 by difference of the refractive indexes between two hemispheres 71a, 71b constituting sphere body 71. In this device, the refractive indexes of hemisphere body 71b, liquid 74, and supporting member 73 are equalized to prevent light refraction at the interface between upper hemisphere body 71b and liquid 74, and at the interface between liquid 74 and supporting member 73. However, this is not essential. The refraction indexes may be different, provided that the driving state and the deflection angle correspond one-to-one. With the light deflection device of this Example, sphere body 71 is driven to turn with the same driving means in the same method as in Example 6.

[0079] When hemisphere body 71 is turned by an angle  $\alpha$  relative to the incident light beam introduced through the bottom of supporting member 73, the angle  $\beta$  of deflection from the incident light beam is shown by the equation below according to Snell's Law:

$$\beta = \sin^{-1}[(n_2 \cdot \sin \alpha)/n_1] - \alpha$$

where  $n_1$  is the refractive index of upper hemisphere body 71b, and  $n_2$  is the refractive index of lower hemisphere body 71a.

[0080] Specifically, the light deflection device is produced in the same manner as in Example 6 except that upper hemisphere body 71b was prepared from a micro-bead having a refraction index of 1.33 and a diameter of 100  $\mu\text{m}$ , and lower hemisphere body 71a was prepared from a micro-bead having a refraction index of 1.9 and a diameter of 100  $\mu\text{m}$  for collimator lens. The reflection layer was not provided at the flat face portion 72. The adhesive used for bonding the two hemisphere bodies was light-transmissive, and had a refractive index equal to that of one of hemisphere bodies 71a, 71b. However, the refraction index is not limited thereto, provided that the driving state and the deflection angle correspond one-to-one each other. After determining the dependence of the deflection angle on the voltage application state preliminarily, hemisphere 1 can be turned under control to obtain a desired deflection angle according to the memorized information of the dependence.

[0081] The arrangement of driving electrodes 76a, 76b, 76c, 76d, and 76e (76d and 76e being not shown in the drawing) relative to sphere body 71 was the same as that in Example 6. On application of a voltage of +100 V between driving electrode 76a and other driving electrodes, sphere body 71 was driven to turn at angle  $\alpha$  of 20° as shown in Fig. 18. After stop of the turning movement, the angle  $\alpha$  kept unchanged without application of the voltage. Further, the light deflection device had excellent stationary positional stability such that the deflection angle was not affected by the change of the attitude of the device. From the above specific numeri-

cal values, the angle  $\beta$  was calculated to be 9° according to the above equation. That is, the reflected light beam was deflected by 9° relative to the incident light beam. The driving control was practicable with reproducibility in any attitude including an upside-down reversed position.

#### Example 9

[0082] The device in this Example has a movable electrode, not chargeable regions, on the sphere body. Fig. 19 is a schematic sectional view of the device of this Example. The device comprises sphere body 71 having flat face portion 72 inside for deflecting an incident light beam, supporting member 73 for supporting sphere body 71 in a turnable manner through a gap, movable electrode 75 at the bottom portion of the spherical face of sphere body 71, and driving electrodes 76a to 76c for applying an electric field under supporting member 73.

[0083] Fixed electrode 78 is provided on the face of supporting member 73 for supporting the bottom of sphere body 71. Fixed electrode 78 is wired, for example, along the internal face of the hemispherical concave of supporting member 73 from the outside. Sphere body 71 turns with movable electrode 75 in contact with fixed electrode 78. A power source is connected to apply a voltage between fixed electrode 78 and driving electrodes 76a to 76c. On application of a voltage between fixed electrode 78 driving electrode 76a to 76c, the voltage comes to be applied between movable electrode 75 in contact with fixed electrode 78 and driving electrodes 76a to 76c, whereby a torque is produced by electrostatic force to turn sphere body 71. Thereby, flat face portion 72 change the direction to deflect the light beam reflected by the reflection layer on flat face portion 72. Fixed electrode 78 is placed to be invariably in contact with movable electrode 75 irrespectively of the turning of sphere body 71.

[0084] The light deflection device was produced generally in the same manner as in Example 6 except the part of the process below. Movable electrode 75 was formed by sputtering of Pt (platinum) by vacuum vapor deposition in the same manner as the formation of the chargeable  $\text{MgF}_2$  region in Example 6. Supporting member 73 was prepared in the same process as in Example 6, and additionally, the face for supporting sphere body 71 on the lower supporting member was coated with Ta (tantalum) by electron beam vapor deposition, and therefrom fixed electrode 78 was formed by photolithography process and etching. Since movable electrode 75 and fixed electrode 78 are invariably in contact with each other, and slide during turning of sphere body 71, materials of high mechanical hardness were employed.

[0085] With the light deflection device thus prepared, dielectric liquid 74 of a silicone oil was filled into the gap between sphere body 71 and supporting member 73, and a voltage was applied between driving electrode



the obtained supporting member 73 having sphere body 71 and lubricating liquid 74 in the cavity is placed between lower glass base plate 77 and upper glass base plate 78, having respectively driving electrodes 76a to 76e and 76f to 76j formed from transparent electroconductive material like ITO. Thus the light deflection device is prepared.

[0092] With the light reflection device prepared above, a voltage, for instance -100 V, was applied to lower driving electrode 76a relative to upper driving electrode 76h. Thereby, sphere body 71 was driven to turn by angle  $\alpha$  of 20° as shown in Fig. 20 to deflect the reflected light by 40°. After completion of the turning movement, the deflection angle of reflection light was kept unchanged without application of the voltage. Further, the light deflection device had excellent stationary positional stability such that the deflection angle was not affected by the change of the attitude of the device similarly as that of Example 6. Further, in this constitution having driving electrodes on the upper and lower base plates, the turning speed was higher by a factor of 2 to 5.

[0093] The process for formation of the supporting member disclosed in this Example is suitable for mass production in consideration of cost reduction and two-dimensional device array formation. In the light deflection element array having light deflection elements arranged two-dimensionally, the respective sphere body can be turned independently to control deflection angle, whereby incident light beams can be deflected two-dimensionally. Such a two-dimensional array can be produced by a relatively simple process at a low cost as follows. A mold is provided which has spherical concaves arrayed on the bottom thereof in an appropriate pitch. The sphere bodies are placed in the concaves. A silicone rubber is filled, cured, and taken out. The bared sphere body portions corresponding to the mold concave positions are covered with additional silicone rubber in another mold by filling, curing, and taking off of the silicone rubber. Then cavities are simultaneously formed by a swelling process.

[0094] As described above, the inside of the supporting member can hold a spherical or segmental spherical turning body by contact at four points at least not on a sphere and at a distance approximate to the turning radius from the turning center. Preferably, the inside shape of the supporting member is point-symmetrical at least three points relative to the turning center (approximate to the distance of radius), and more preferably, spherically symmetrical to drive stably the spherical or segmental spherical turning body irrespectively of the attitude of the device. Further, the turning body designed to be in a shape of sphere or approximate thereto to coincide approximately the turning center and the gravity center will give excellent stationary positional stability without producing torque resulting from gravity and buoyancy, and resistant to external vibration.

[0095] Furthermore, by applying the turning force to

the spherical face of the turning body, the torque application point is invariably at the distance of radius from the turning center point to facilitate the control of the turning direction and angle of the turning body, to make the device simpler and suitable for miniaturization and array construction. Thereby, a light deflection device is provided in which the turning range of the turning body can be made larger to obtain a larger light deflection angle. Furthermore, non-contacting driving of the turning body makes easier the sealing of a liquid like a dielectric liquid around the turning member.

[0096] A light deflection device comprises a deflection member having a sphere body enclosing a deflection face portion for deflecting a light beam, or a segmental sphere body having the deflection face portion and a segmental sphere face opposing to the deflection face portion, a supporting member for supporting the deflection member in a turnable manner, and a driving means for turning the deflection member, said driving means being provided on the sphere face or the segmental sphere face of the deflection member, and at a position opposing to the sphere face or the segmental sphere face of the deflection member to apply a driving force to the sphere face or the segmental sphere face.

[0097] A light deflection device array comprises the arrangement of light deflection devices in one-dimensional or two-dimensional array.

## Claims

### 1. A light deflection device comprising:

a deflection member having a sphere body enclosing a deflection face portion for deflecting a light beam, or a segmental sphere body having the deflection face portion and a segmental sphere face opposing to the deflection face portion;

a supporting member for supporting the deflection member in a turnable manner; and

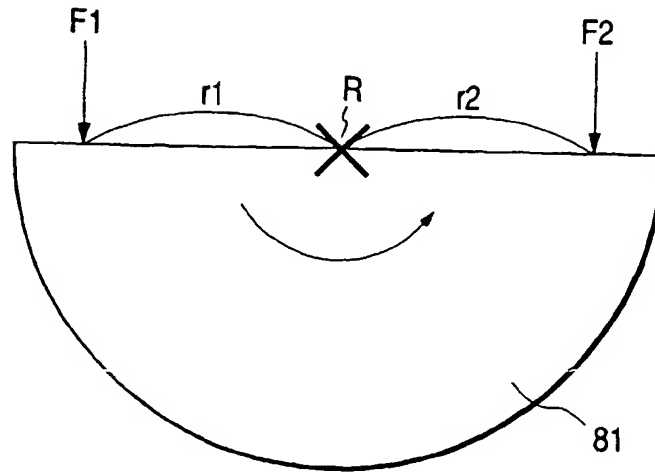
a driving means for turning the deflection member, said driving means being provided on the sphere face or the segmental sphere face of the deflection member, and at a position opposing to the sphere face or the segmental sphere face of the deflection member to apply a driving force to the sphere face or the segmental sphere face.

2. The light deflection device according to claim 1, wherein the deflection member is the segmental sphere body, the supporting member has a concave having internal face in a shape of a segmental sphere face, and the segmental sphere body is placed in the concave.

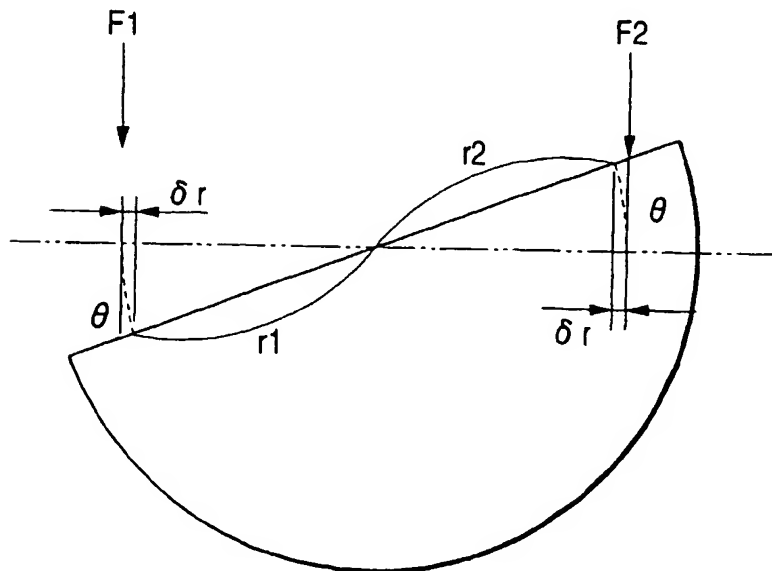
3. The light deflection device according to claim 2, wherein a gap is provided between the segmental



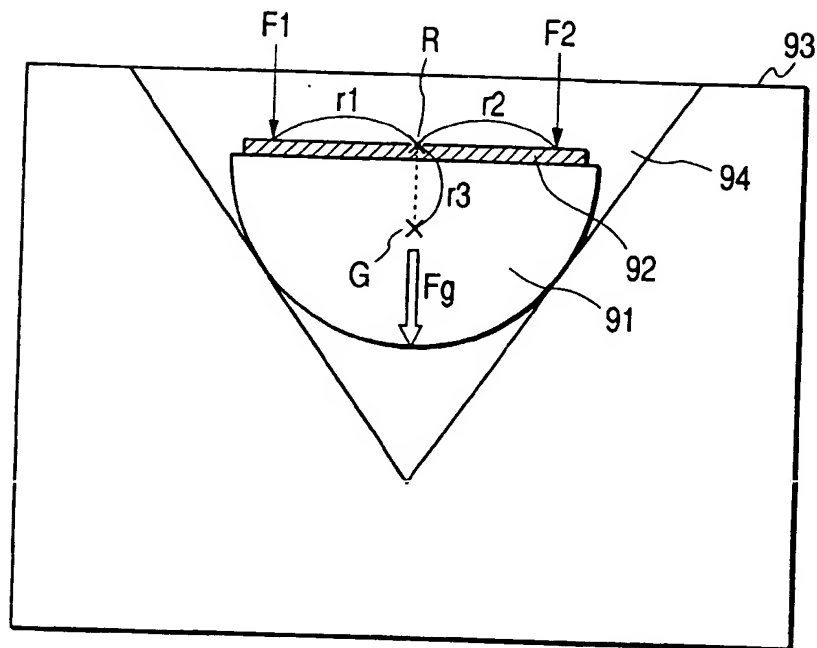
*FIG. 1A PRIOR ART*



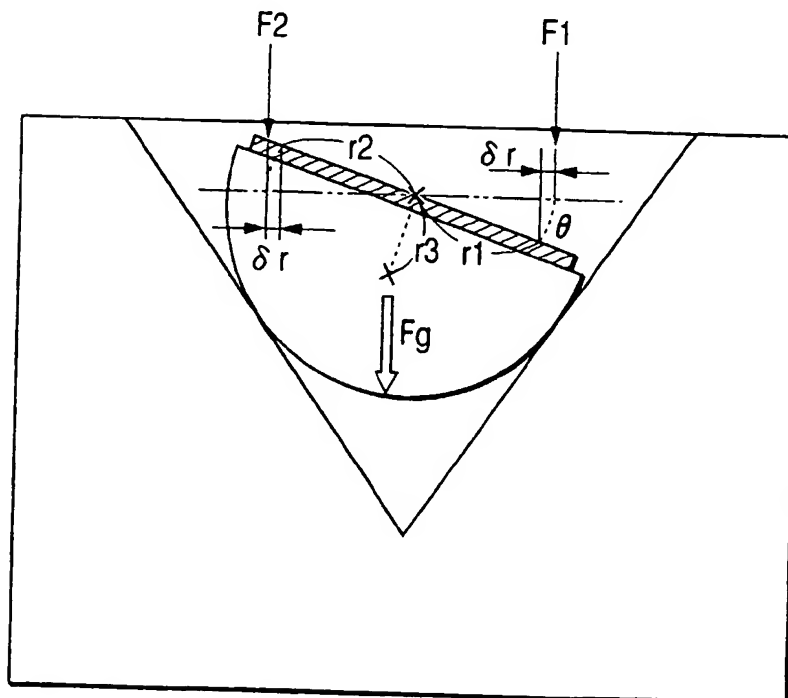
*FIG. 1B PRIOR ART*



*FIG. 3A PRIOR ART*



*FIG. 3B PRIOR ART*



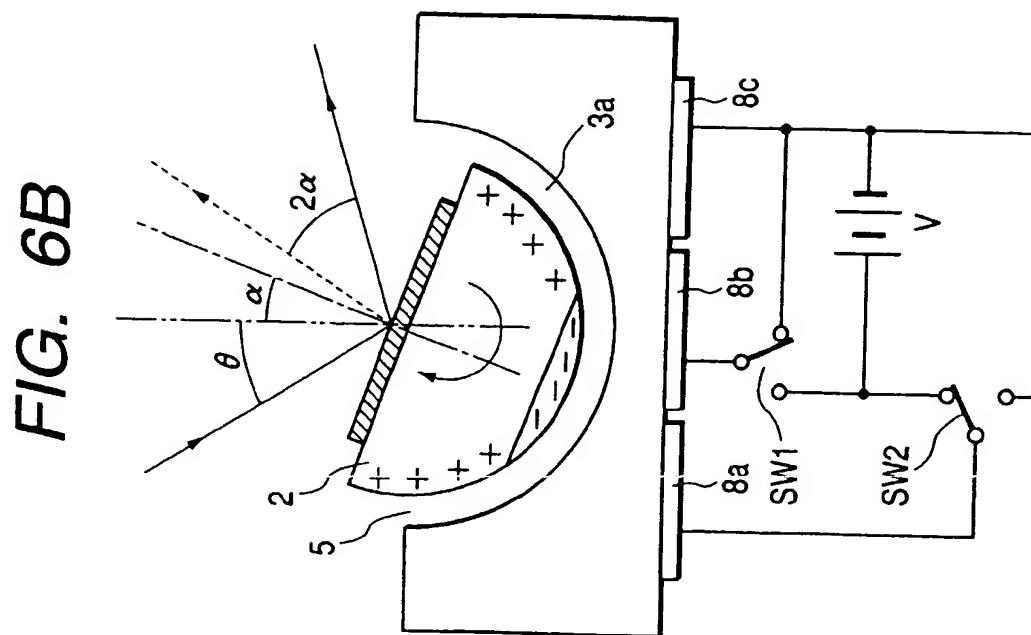
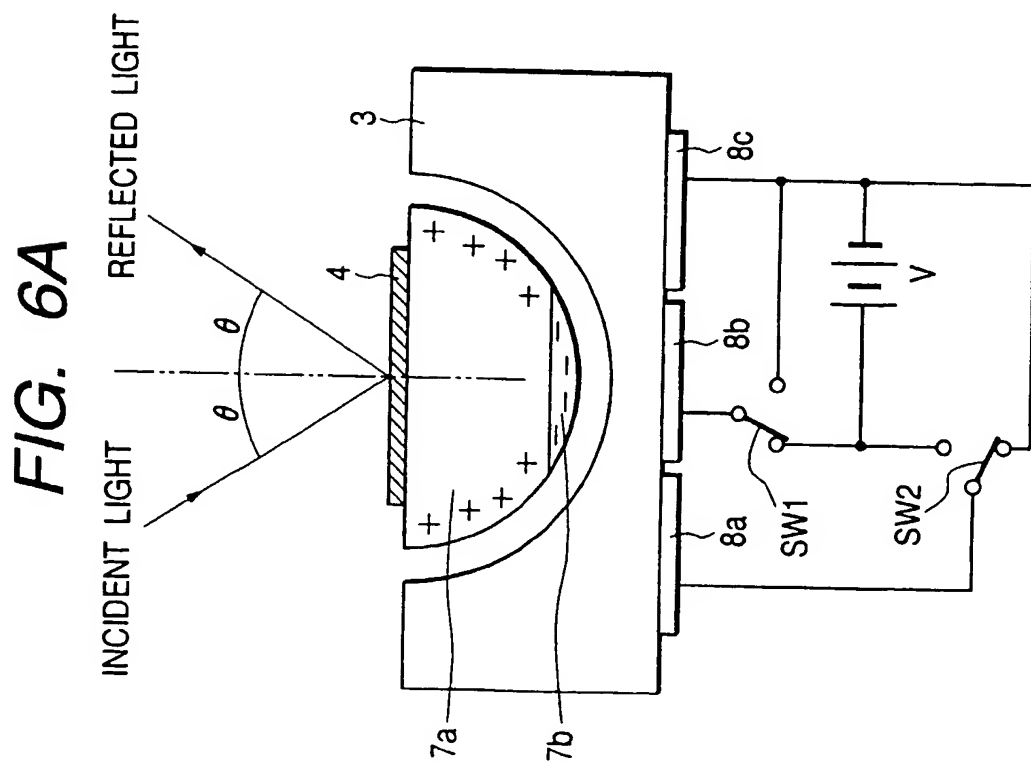


FIG. 9

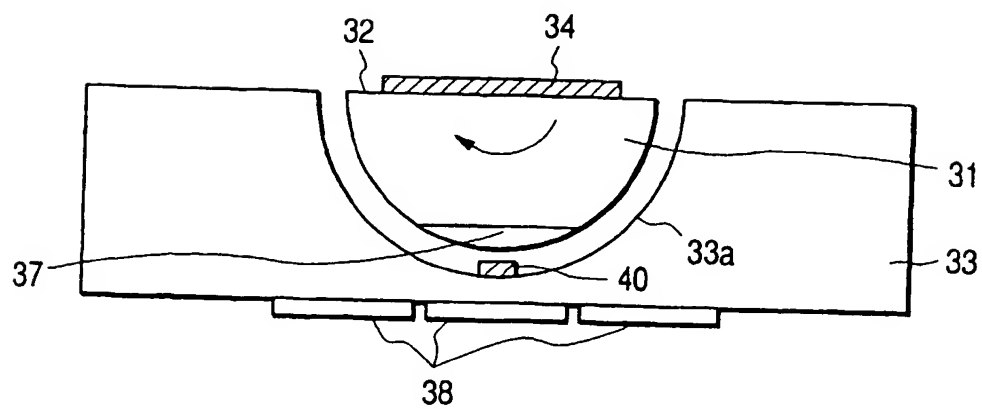


FIG. 11

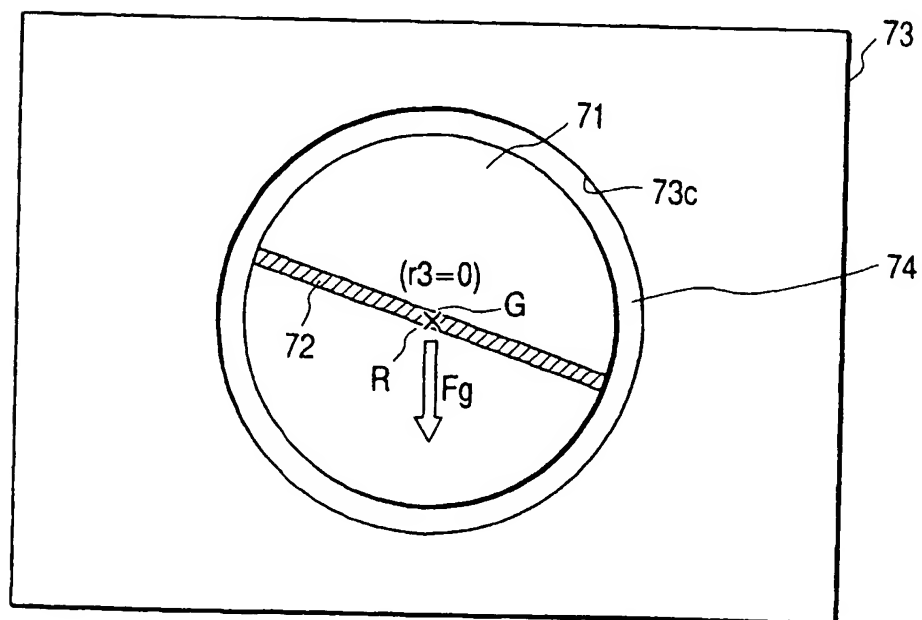


FIG. 12

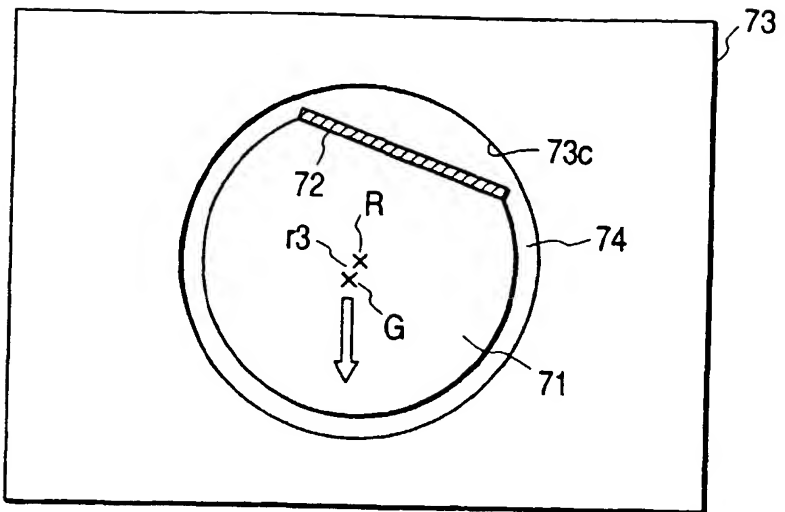


FIG. 13

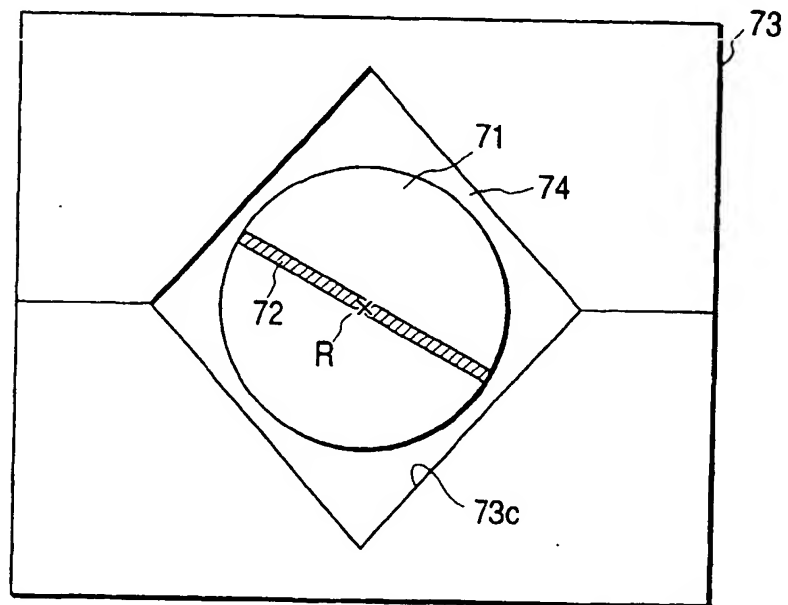


FIG. 14

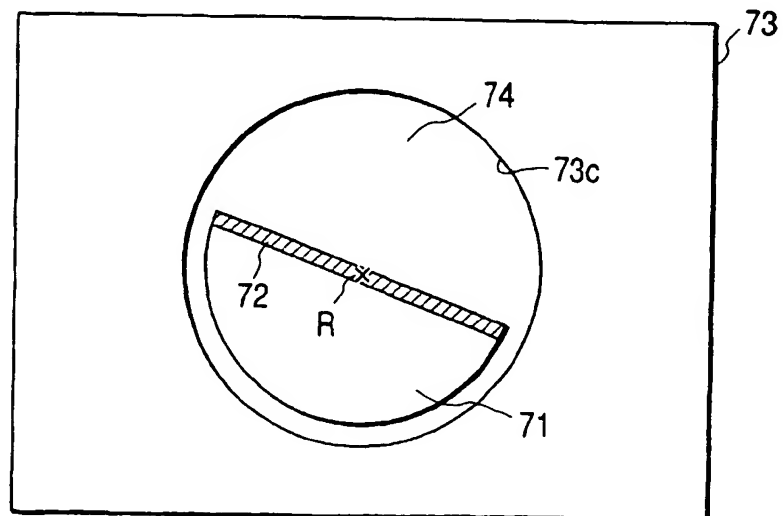


FIG. 16A

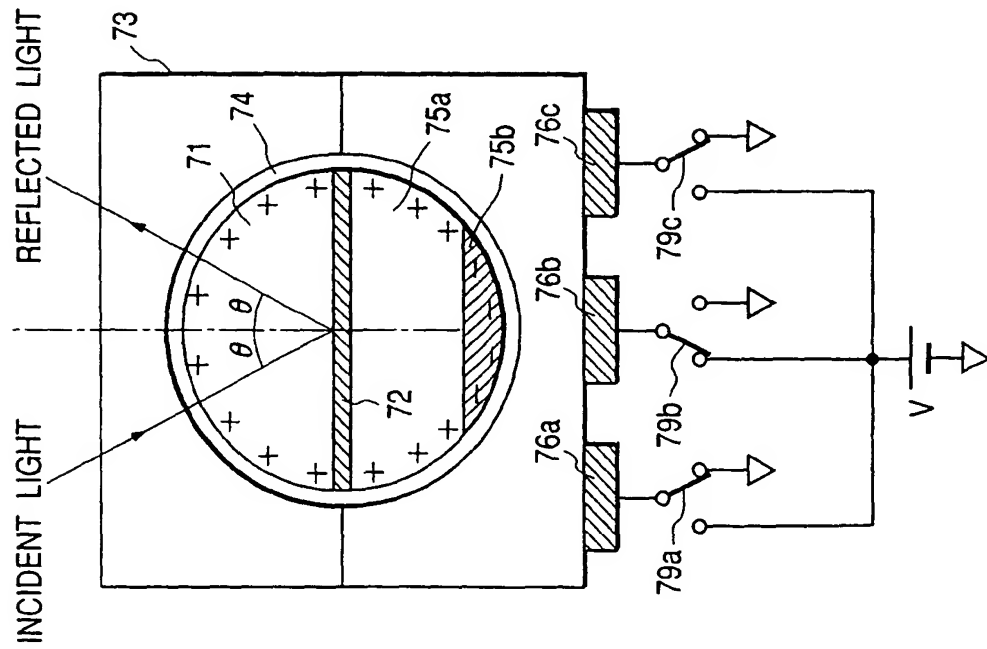


FIG. 16B

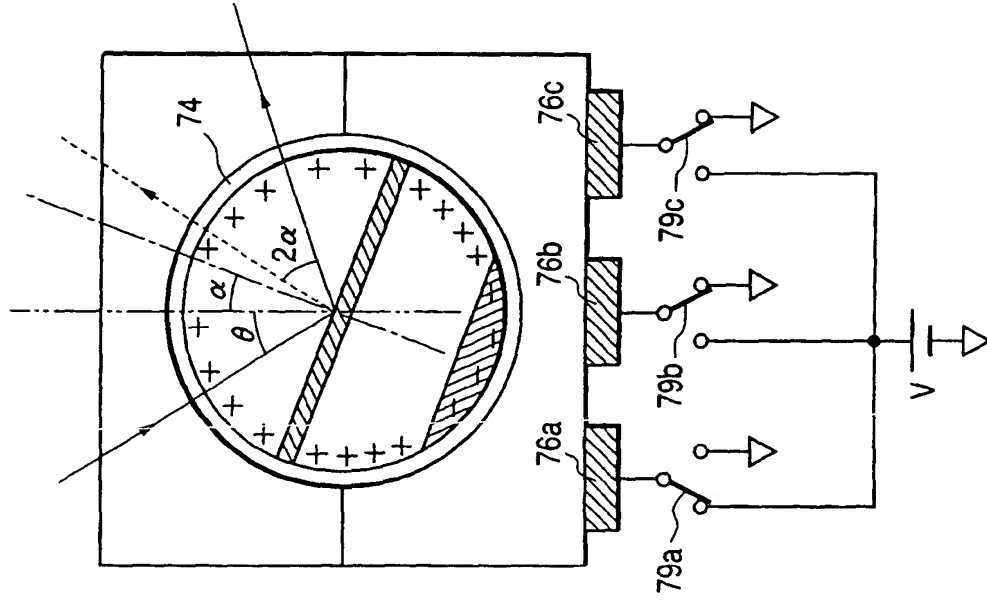


FIG. 19

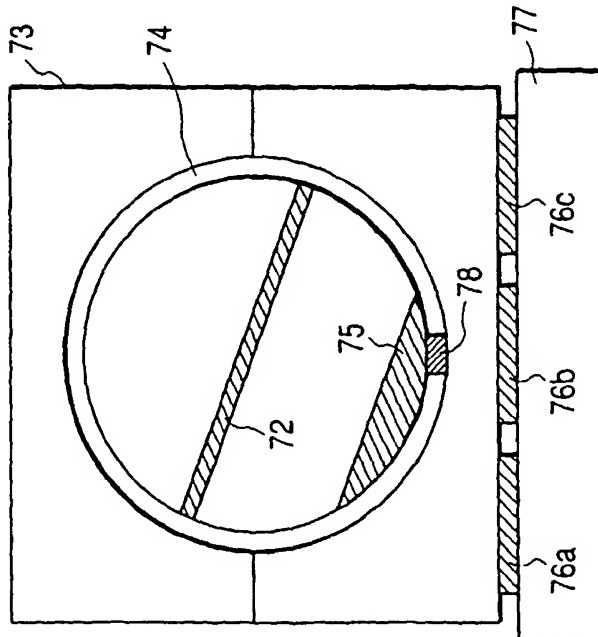
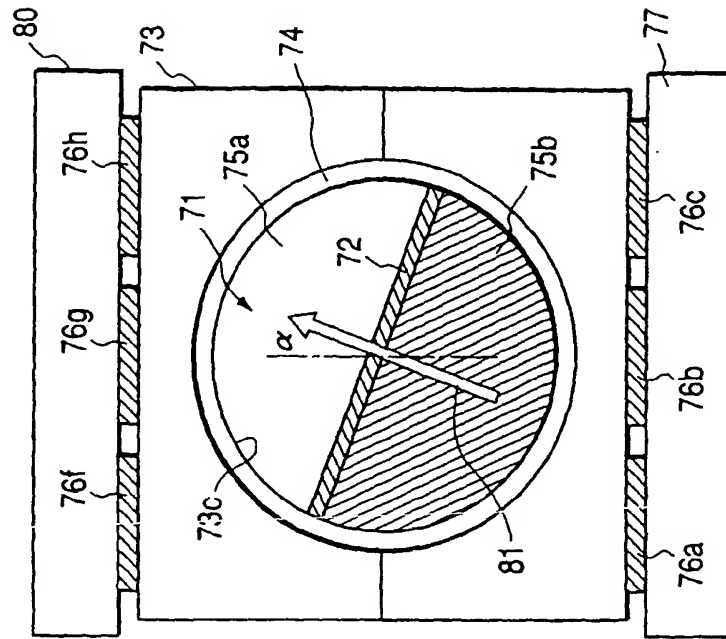


FIG. 20







European Patent  
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# EUROPEAN SEARCH REPORT

Application Number  
EP 98 12 1705

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	WO 93 06510 A (HELL AG LINOTYPE) 1 April 1993 * abstract; figure 1 *	1, 16	
A	PATENT ABSTRACTS OF JAPAN vol. 005, no. 021 (P-048), 7 February 1981 & JP 55 147602 A (FUJITSU LTD), 17 November 1980 * abstract *	1, 14, 16, 17	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 5 February 1999	Examiner Ciarrocca, M
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

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